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THE EFFECT OF SIGNAL INCIDENCE ON DETECTABILITY.(U)

APR 68 J M YOUNG NOBSR-95149

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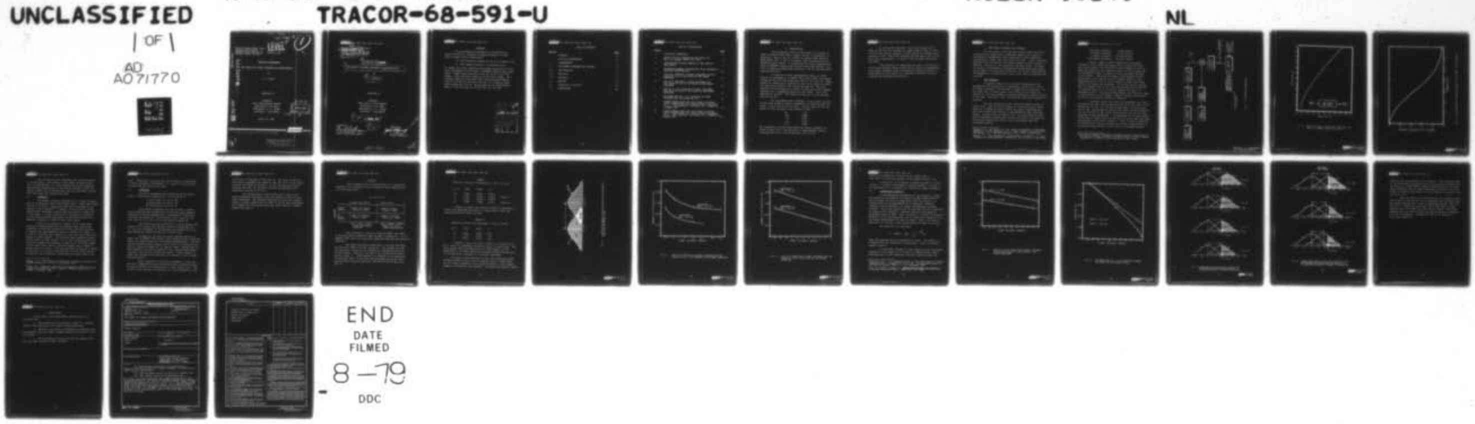

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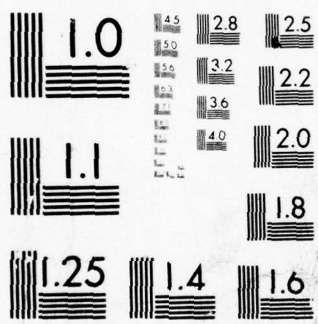

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Contract NObsr-95149 Mod 2
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Document Number 68-591-U

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TECHNICAL MEMORANDUM

THE EFFECT OF SIGNAL INCIDENCE ON DETECTABILITY

by

J. M. Young

Submitted to

Commander
Naval Ship Systems Command
Department of the Navy
Washington, D. C. 20360
Attention: Code PMS-87

April 16, 1968

TRACOR
6500 Tracor Lane, Austin, Texas 78721, AC 512/926-2800

TRACOR 6500 TRACOR LANE, AUSTIN, TEXAS 78721

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TECHNICAL MEMO[redacted]

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Head, Psychology Section

Submitted:

J. M. Young
Project Director

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ABSTRACT

An experimental determination of probability of detection P(D) as a function of signal incidence, SI (how often a signal occurs) showed that:

1) P(D) decreases linearly as the SI is reduced, and

2) P(D) remains finite as SI approaches zero.

To conduct the tests, observers were shown projections of film strip photographs of the output of TRACOR's digital sonar simulator. Signals were injected in 10%, 5%, 1% or 0.1% of the frames; noise alone was presented in the other frames. At a constant signal-to-noise ratio S/N, P(D) decreased linearly from 0.82 at 10% SI to 0.48 at 0.1% SI, at a constant false alarm probability of 0.01. The decrease in the detectability index d' over this span of SI was from 3.21 to 2.28.

TRACOR 6500 TRACOR LANE, AUSTIN, TEXAS 78721

TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

1. INTRODUCTION

An experimental study has been made of the effect of signal incidence (how often a signal occurs) on probability of detection. This is one of a series of studies under Contract NObsr-95149, Mod 2, Task 2 to enhance fleet utilization of the AN/SQS-26 sonar system. In conducting this study, advantage was taken of TRACOR's unique sonar display simulation facility, its pool of trained psychophysical observers, and its efficient data handling processes.

In contrast to most psychophysical tests, in which signals are presented in a nominal 50% of the trials, the signal incidences (SI) for this study were 10%, 5%, 1%, and 0.1%. Equal numbers of signals were presented at each SI in order to achieve the same error bounds on the results for each SI. The test material for this study was a series of film strips with signals injected into a designated percent of the frames. SI is thus expressed in percent. The signal-to-noise ratio (S/N) was the same for all SI.

Two experiments were conducted. In the first, a value of S/N large enough to yield a probability of detection P(D) of about 0.5 at an SI of 0.1% was used. At this value of S/N, the values of P(D) obtained at the various SI were

SI	P(D)
10%	0.820
5%	0.675
1%	0.530
0.1%	0.484

The probability of false alarm P(FA) was almost constant at a value of about 0.01. The decrement in detectability index d′ in going from 10% to 0.1% SI was from 3.21 to 2.28.

In the second experiment, only three values of SI (10%, 5% and 1%) were studied at a lower value of S/N, in order to see if the rate of decrease of P(D) with SI is constant as a function of S/N. The values obtained for P(D) were 0.514, 0.355, and 0.255, respectively. A value of 0.01 was again maintained for P(FA).

The procedure for conducting the tests, a description of the test material (film strips) and its manner of preparation, and a short statement about the observers constitute Section 2. A discussion of the results is contained in Section 3 and conclusions are presented in Section 4.

2. THE SIGNAL INCIDENCE TEST PROGRAM

For many years, there has been concern about the ability of observers to detect weak, infrequent signals (in a noise or reverberation background), whose occurrence is both temporally and spatially random, over long periods of time[1]. Such a situation represents the one faced by the sonar observer at sea who must, in addition, operate at a low probability of false alarm. The Navy, of course, is interested in determining minimum detectable signal levels (MDL), in operational situations. To do this realistically, the degradation in detectability due to rare signal occurrence must be known.

2.1 TEST MATERIAL

An earlier study on this contract[2] demonstrated the feasibility and practicality of conducting a study of the effect of signal incidence on an observer's probability of detection. It was shown that to obtain equal error bounds on the results for various SI, the total number of signals presented at each SI should be the same. Obviously, then, for lower SI, more test material is required.

The test material for this study was several series of film strips. Each of the 150 frames of a film strip was a photograph of a cathode ray tube on which was shown a simulated six echo cycle single beam history of the AN/SQS-26 signal processor output. Using a value of 0.023 as the $\pm 1\sigma$ error bounds on P(D) and 16 independent observations of each film strip, the number of film strips required for each SI was in accordance with the following schedule:

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[1] Bergum, B.O., and Klein, I.C.,"A Survey and Analysis of Vigilance Research," George Washington Univ., Human Resource Research Office Washington, D.C., Research Report 8, Nov., 1961, (AD 267 233).

[2] Young, J.M., "The Feasibility of Determining the Effect of Signal Incidence on Detectability", TRACOR Doc. No. 67-944-U, 2 Nov. 1967.

10% Signal Incidence - 2 Film Strips,
5% Signal Incidence - 4 Film Strips,
1% Signal Incidence - 20 Film Strips,
0.1% Signal Incidence - 200 Film Strips.

Figure 1 shows in block diagram form the digital simulation of the signal processor used in conjunction with the A-scan display. The 24-channel serial OR-gate is used to match the display to the signal processor so that no more than one independent sample is placed in each resolvable location on the display. Since the 24-channel serial OR-gate selects and outputs to the display only the largest sample in each sequential block of 24, a loss in signal-to-noise ratio (S/N) results from using this technique. It has been shown, however, that the OR-gate loss is less than that encountered if the CRT is saturated with all of the output samples and used as an averaging device[3]. The relationship between the S/N at the input to the 24-channel serial OR-gate (signal processor output) and the S/N at the output is plotted in Figure 2.

A constant signal level was used throughout the first experiment such that the average value of S/N at the input to the display was 9.3 dB. For the second experiment, the value used was 6.9 dB. Corresponding values at the output of the correlator are 12.2 dB and 10.5 dB. These latter values are cited in the remainder of this memorandum. The magnitude of the noise sample at the time of signal injection may have any value under the noise distribution curve shown in Figure 3. There is thus a variation of S/N from one echo cycle history to the next representative of the ping-to-ping variation in S/N found in recorded sea data.

[3] "Analysis of Signal Processing and Related Topics Pertaining to the AN/SQS-26 Sonar Equipment-A Summary Report, II (U)," TRACOR Document No. 64-290-C, p.181, October 16, 1964 (CONF).

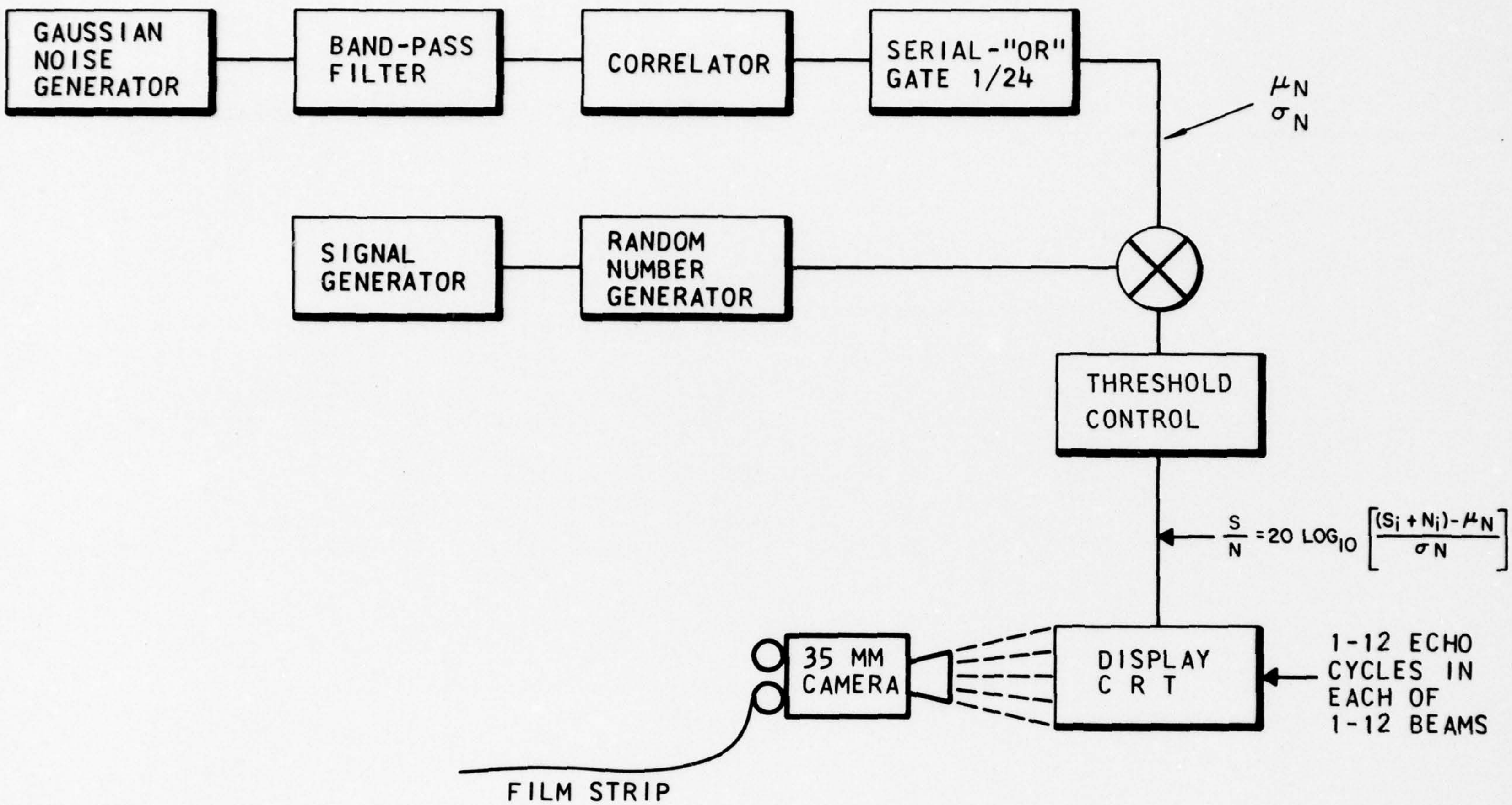

FIG. 1 - FILM STRIP GENERATION

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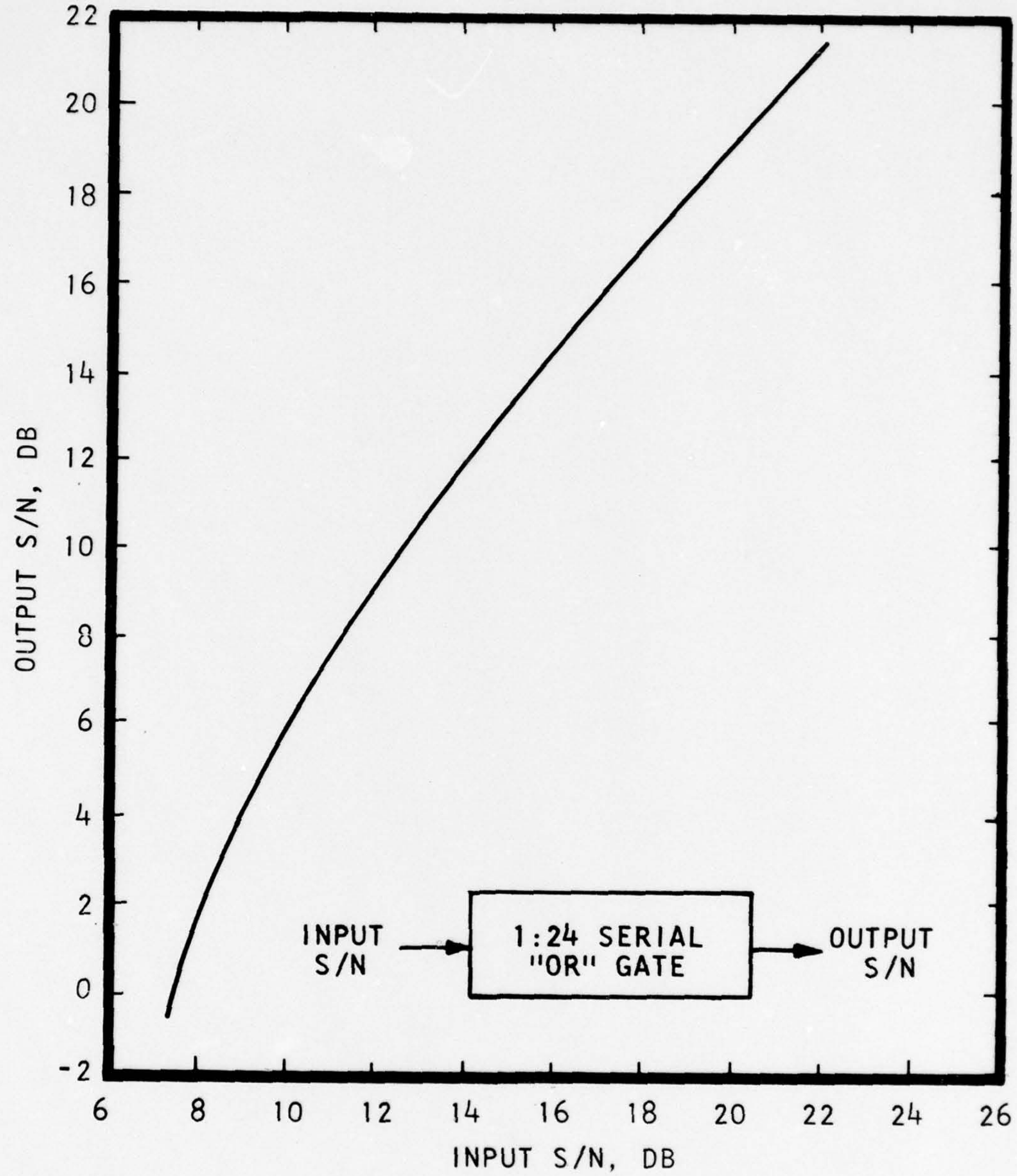

FIG. 2 - OUTPUT S/N AS A FUNCTION OF THE INPUT S/N FOR A 24 CHANNEL SERIAL "OR" GATE

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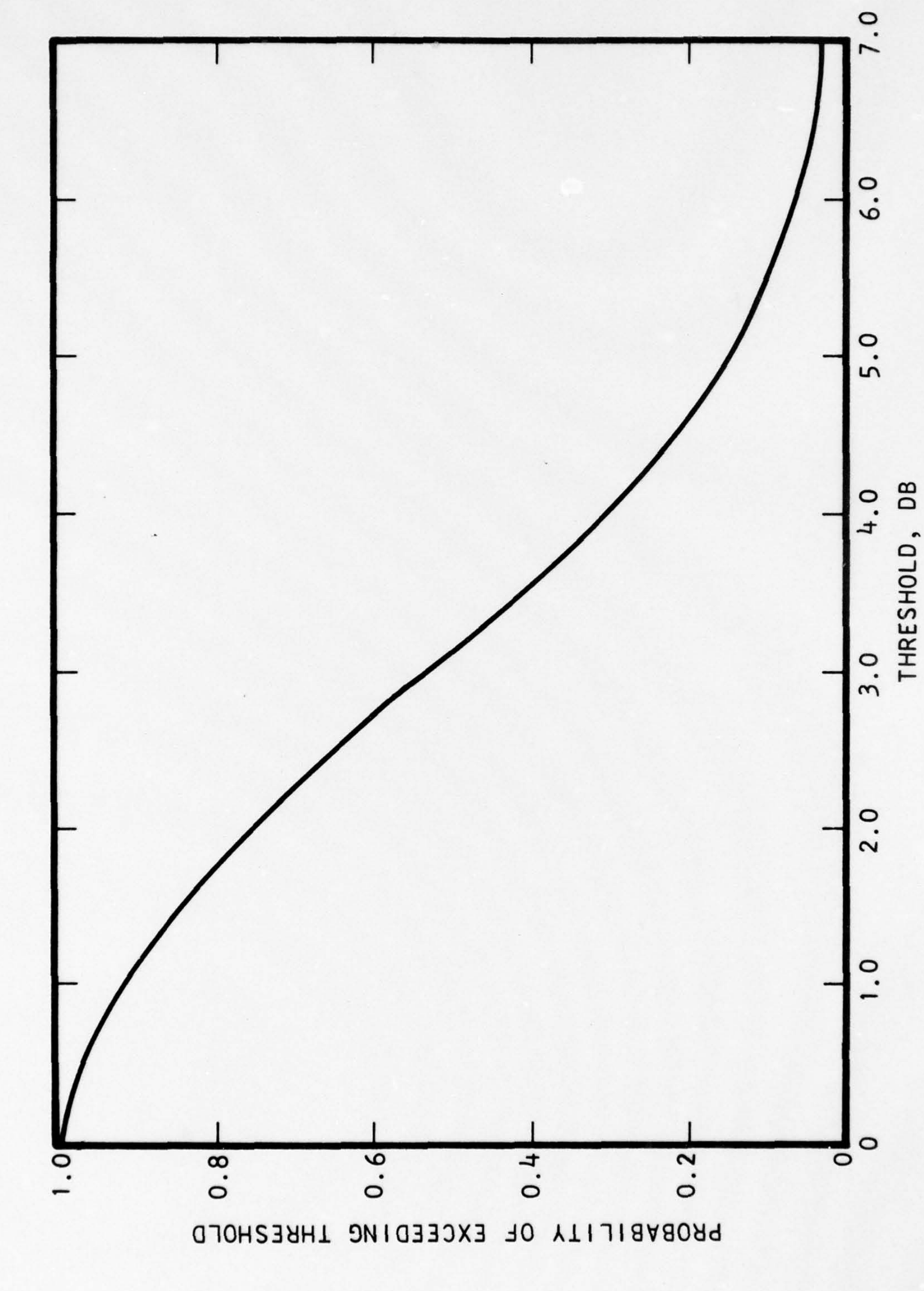

FIG. 3 - DISTRIBUTION OF NOISE SAMPLES AT THE INPUT TO THE DISPLAY

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The intensity of each displayed mark was proportional to its amplitude. The samples at the signal processor output were not thresholded, i.e, unity marking density was employed. The intensity (brightness) of the CRT was adjusted so that the largest samples did not occupy more than one resolvable location. Only zero range rate signals were used.

2.2 OBSERVERS

The sixteen observers employed for the signal incidence test were young adult males with normal vision. Their ages ranged from 18 to 23 years; they had all had prior experience as observers on this contract[4,5]. However, in all of their earlier observational experience signals had been present in about 50% of the frames. In some of the work[5] a rating scale technique had been employed which engendered lax decision criteria and a subsequent tendency to make too many false alarms.

Since it was desired to conduct the SI study under conditions approximating those encountered under operational conditions, a very low probability of false alarm was desired. In working with psychophysical subjects (observers) however, it is easy to influence their behavior so that they never make false alarms or detect signals. The observers were therefore trained to make about 1% false alarms, i.e, in each 150-frame film strip they were allowed, and required, to make one or two false alarms. A false alarm occurs when an observer decides that a signal is present when one is not. Since each decision is based on a single observation of a six echo cycle history, the term "false alarm" as used here has a different significance from that used by the

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[4]Young, J. M., "The Effect of Range Rate on Signal Detectability," TRACOR Document No. 67-800-U, 16 October 1967.

[5]Young, J.M., "Receiver Operating Characteristic (ROC) Curves for a Simulated AN/SQS-26 A-Scan Display," TRACOR Document No. 67-1088-U, 10 January 1968.

Navy. Furthermore, each six echo cycle history is independent of those preceding or following, i.e., there is no carry-over of data from one frame to the next.

2.3 PROCEDURE

The first experiment was carried out in two phases. Phase I consisted of presentation to 16 observers of:

2 film strips at a SI of 10%
4 film strips at a SI of 5%
20 film strips at a SI of 1%

Since Phase I required only some 10 days, a rather quick indication was obtained that the S/N was large enough to overcome the expected degradation in probability of detection P(D) with decreasing SI. The goal was to use a value of S/N such that for an SI of 0.1% the P(D) would be about 50%.

The film strips were presented in a random manner with respect to SI so that the observers could not anticipate the SI. The only "feedback" to the observers was whether they were maintaining the desired probability of false alarm.

In Phase II, the 200 film strips (30,000 frames), in which only 30 signals were present, were viewed by the 16 observers. Again, the signal occurrence was random (unpredictable). The time interval between signals ranged from as short as 10 seconds (signals in successive frames) to as long as a week. During each two hour observation period the observers were presented 600 frames of data at the rate of 6 frames per minute. After viewing each frame they recorded their decision as to whether or not a signal had been present.

After completion of the first experiment, it was realized that comparatively little additional effort would be needed to repeat the Phase I observations at a lower value of S/N. The results should provide an indication as to the dependence on S/N

of the rate of decrease of P(D) with SI. The value of S/N for this second experiment was chosen so that for an SI of 10% a P(D) of about 0.50 would be obtained. It was felt that the results obtained from 10%, 5%, and 1% SI could be extrapolated with sufficient accuracy to 0.1% SI.

The observations of the 26 film strips used in the second experiment were made in the same manner as those for the first experiment. The observers were glad to have more opportunities to detect signals than in Phase II of the first experiment even though they soon became aware that their ability to detect signals was poorer.

3. RESULTS

After completion of all observations for a particular condition, the responses of the 16 observers were summarized in the following manner:

STIMULUS

RESPONSE	Signal plus Noise	Noise Alone
Signal Present	Number of Signals Detected, N(D)	Number of False Alarms, N(FA)
No Signal Present	Number of Signals Missed, N(M)	Number of Correct Rejection, N(CR)
	N(S) = N(D) + N(M) = number of signals presented	N(N) = N(FA) + N(CR) = number of noise alone presentations

The quantities of interest, P(D) and P(FA), are found by dividing N(D) and N(FA) by N(S) and N(N), respectively. It is apparent that these two quantities completely describe the observers' responses.

The values obtained in Experiment 1 for P(D) and P(FA) are listed in Table I for the various SI. The decrease in P(D) and the almost constant value of P(FA) for decreasing values of SI are obvious. Also shown in Table I are values of the detectability index, d′. This quantity is a measure of the separation of the mean values of the noise (N) and signal-plus-noise (S+N) distributions along the observer's decision criterion axis (see Fig. 4).

TABLE I

Observers' Results for Experiment 1, S/N = 12.2 dB

SI, %	P(D)	P(FA)	d′	
10	0.820	0.011	3.21	Phase I
5	0.675	0.013	2.79	
1	0.530	0.008	2.40	
0.1	0.484	0.009	2.28	Phase II

Table II contains the results obtained in Experiment 2. Since this experiment was made at a lower value of S/N, the resulting values of P(D) are lower.

TABLE II

Observers' Results for Experiment 2, S/N = 10.5 dB

SI, %	P(D)	P(FA)	d′
10	0.514	0.011	2.31
5	0.355	0.009	1.95
1	0.255	0.012	1.67

Figures 5 and 6 are plots of P(D) as a function of SI; SI is shown on logarithmic and linear scales in these plots. The error bounds about the data points in these figures are the theoretical $\pm$ 1σ limits based on an assumed binomial distribution of the observers' responses in a "yes-no" experiment.

The nearly linear decrease in P(D) with decreasing signal incidence shown in Fig. 6 was not expected since a finite P(D) at zero signal incidence is the logical extension. This apparent enigma is resolved by the statement: No matter how rarely a signal

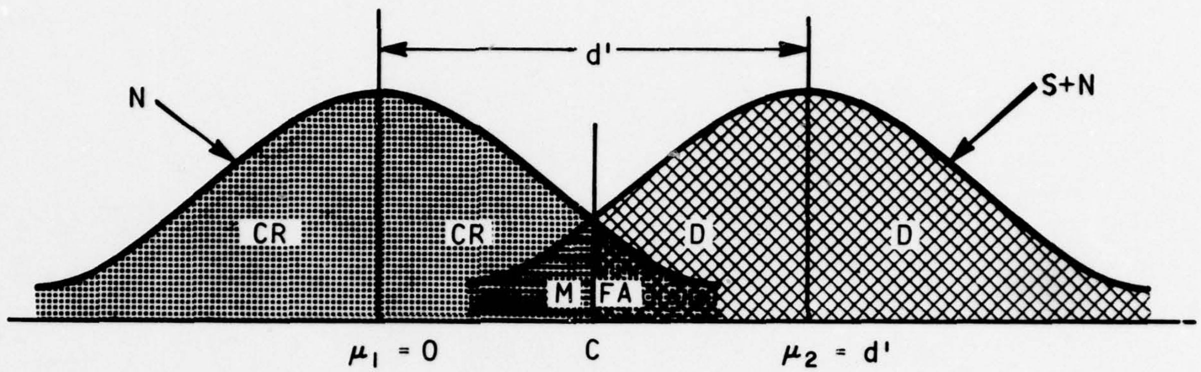

FIG. 4 - OVERLAPPING NORMAL DISTRIBUTIONS ON AN OBSERVER'S DECISION CRITERION AXIS.

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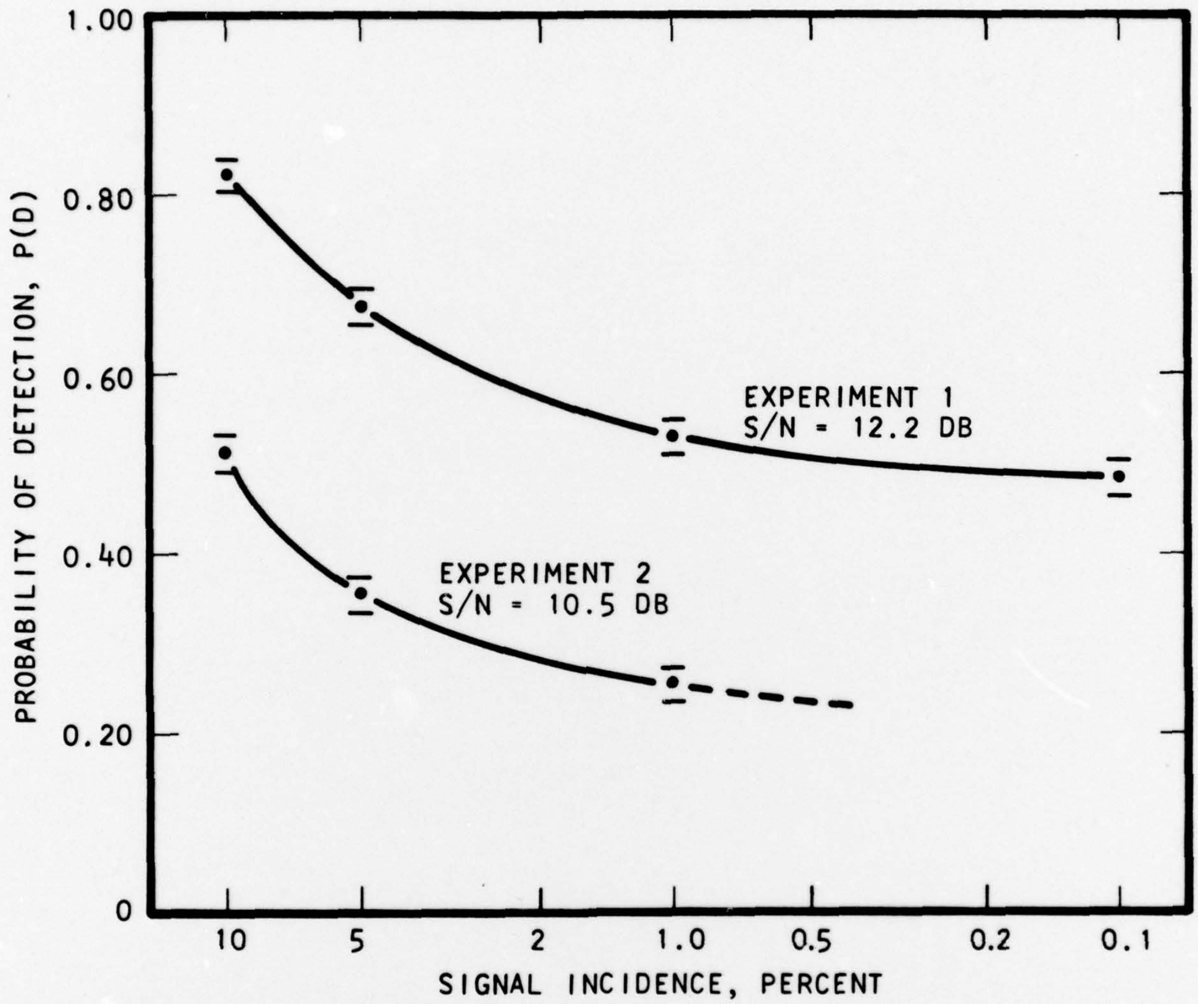

FIG. 5 - P(D) AS A FUNCTION OF SIGNAL INCIDENCE FOR TWO VALUES OF S/N AT THE OUTPUT OF THE SIGNAL PROCESSOR.

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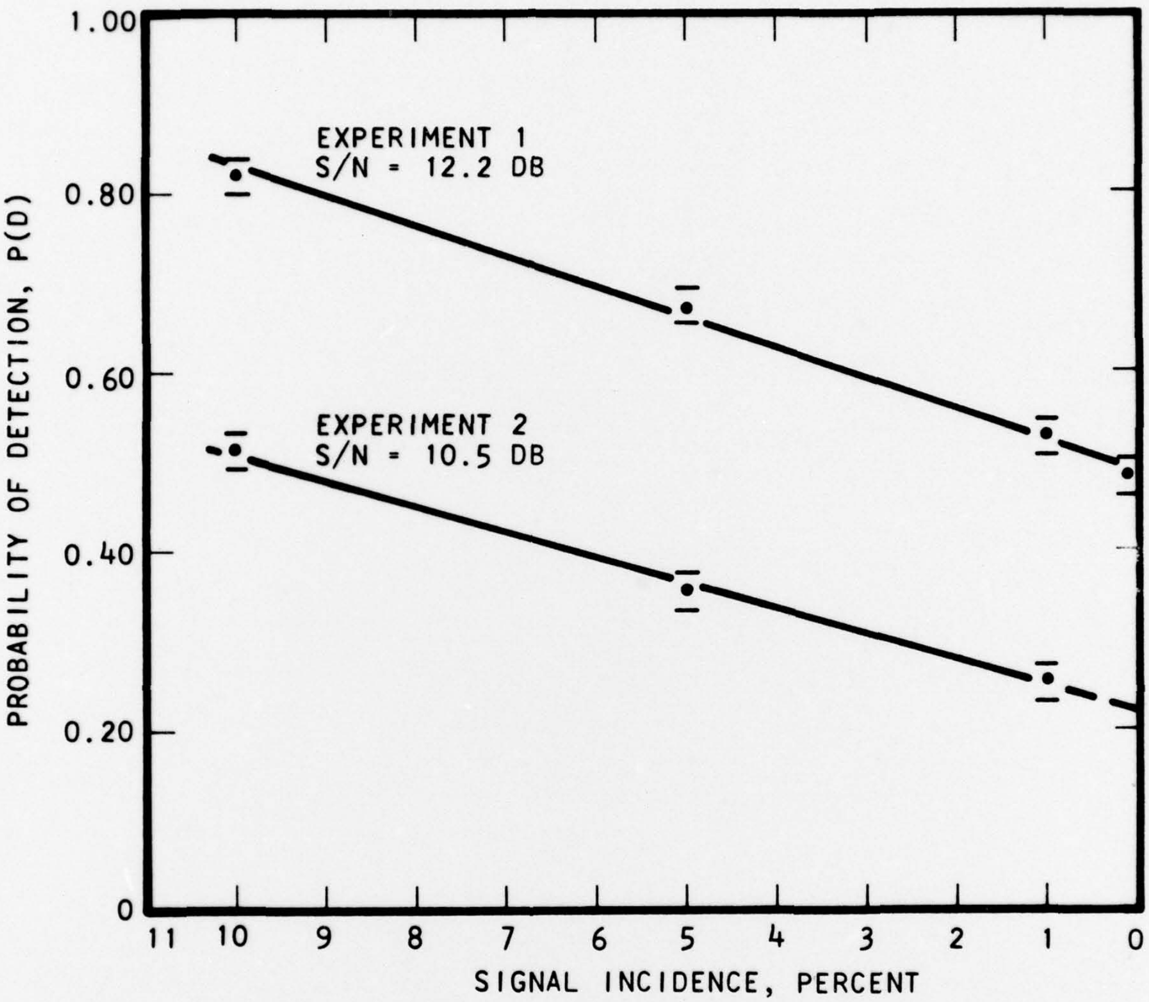

FIG. 6 - P(D) AS A FUNCTION OF SIGNAL INCIDENCE FOR TWO VALUES OF S/N AT THE OUTPUT OF THE SIGNAL PROCESSOR.

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occurs, the probability of detecting the signal when it does occur is finite and depends on the signal-to-noise ratio.

A plot of d′ as a function of signal incidence is shown in Fig. 7. A linear relationship is again exhibited. In Fig. 8 the reduction in d′ is plotted as a function of signal incidence.

3.1 DISCUSSION OF RESULTS

A straightforward explanation of the observers' results and behavior is provided by the Theory of Signal Detectability[6] if one assumes for ease of manipulation that the N and S + N distributions can be represented on the observer's decision criterion axis as Gaussian, or normal, distributions of equal variance. Since more decisions by far are made for the N condition, an observer will establish a decision criterion that gives an acceptable value of P(FA). This criterion, C, in units of standard deviation of the N distribution, can be found from a tabulation of the normal distribution[7] if P(FA) is known. There is no loss in generality if the mean of the N distribution is taken to be zero.

The value of C is found from

$$[1 - P(FA)] = \frac{1}{\sqrt{2\pi}} \int_{\infty}^{C} e^{-\frac{x^2}{2}} dx ,$$

where the variance has been normalized to unity. The values of C obtained for the various SI in Experiments 1 and 2 are shown in Figures 9 and 10.

Of particular interest in these figures is the decreasing separation of the means of the N and S + N distributions, which indicates that, on the observers' decision criterion axis, the

[6] Peterson, W.W., T. G. Birdsall and W. C. Fox, "The Theory of Signal Detectability," Transactions of the IRE. Professional Group on Information Theory, PGIT-4, p. 171, September 1954.

[7] See, for example, Cramér, H., Mathematical Methods of Statistics, Princeton University Press, Table I, p. 557, 1946.

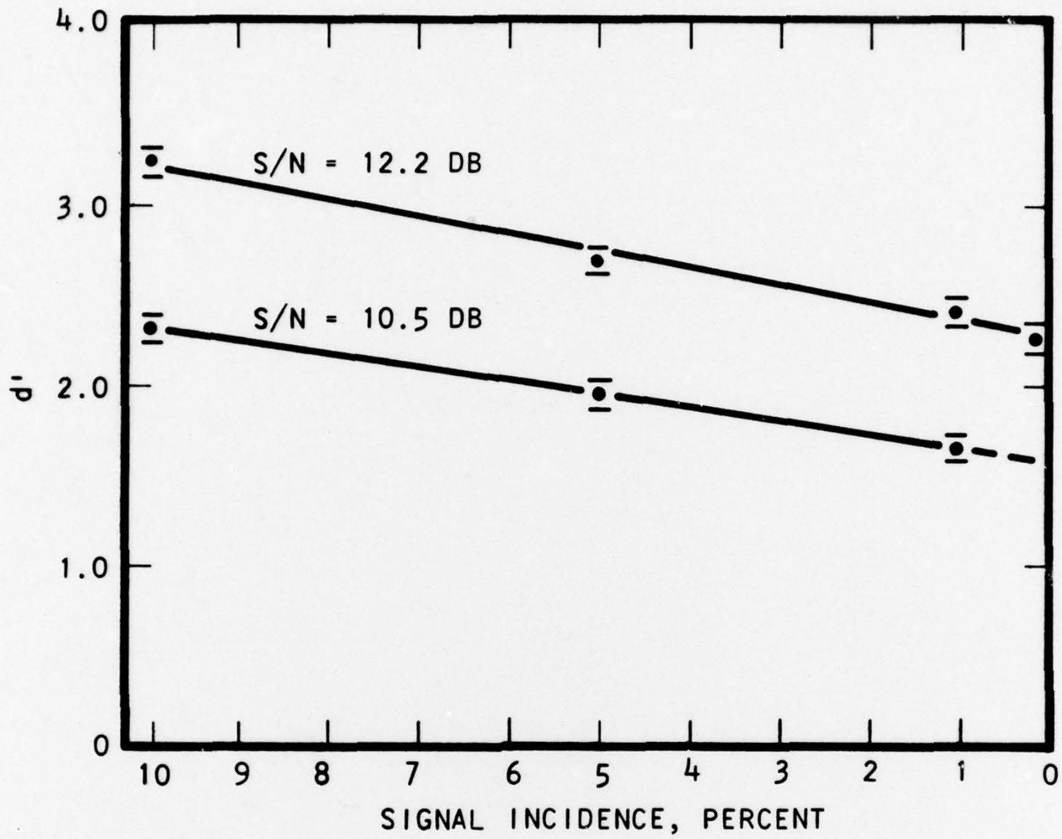

FIG. 7 - PLOT OF d' AS A FUNCTION OF SIGNAL INCIDENCE FOR TWO S/N VALUES AT THE OUTPUT OF THE SIGNAL PROCESSOR.

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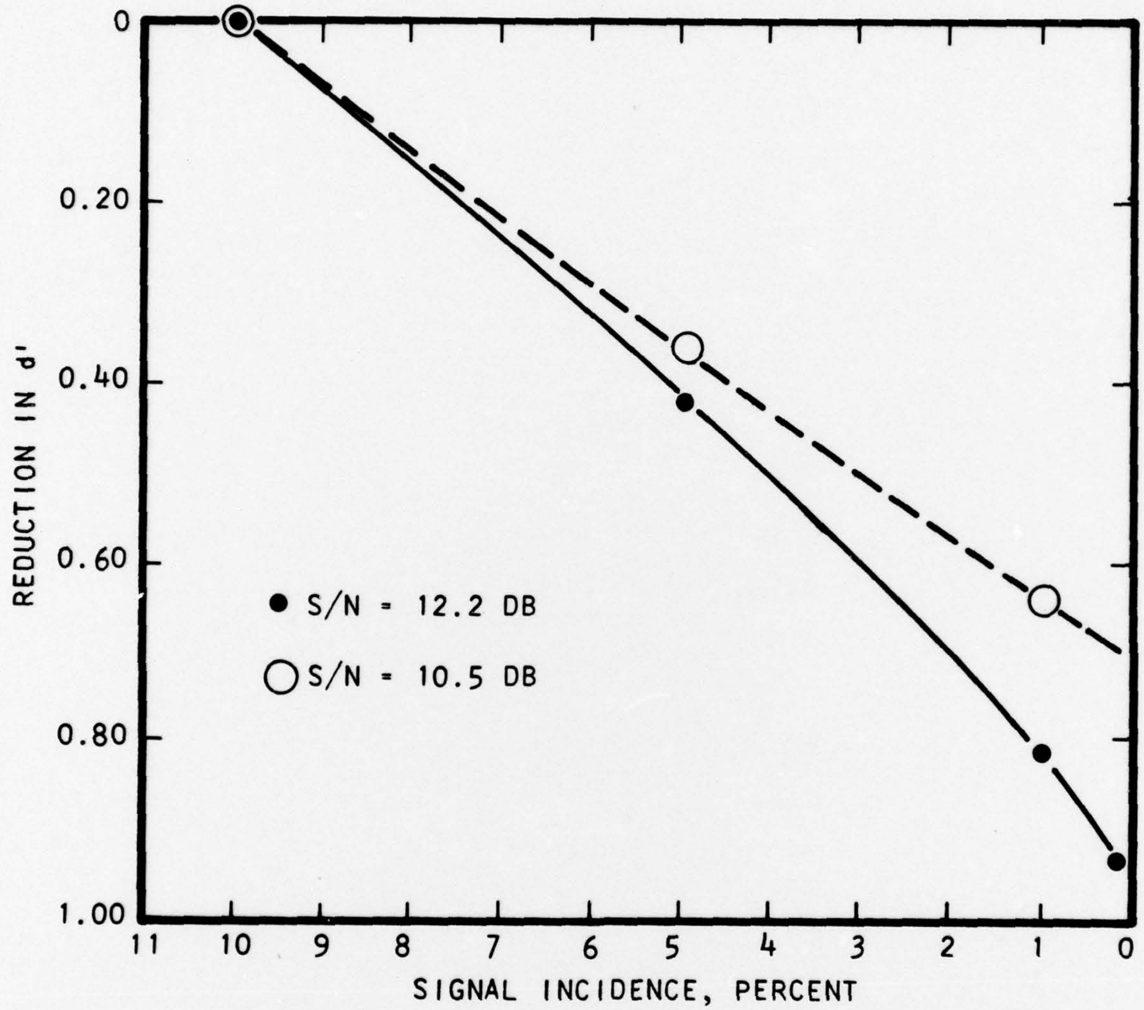

FIG. 8 THE REDUCTION IN d' AS A FUNCTION OF SIGNAL INCIDENCE FOR TWO VALUES OF S/N

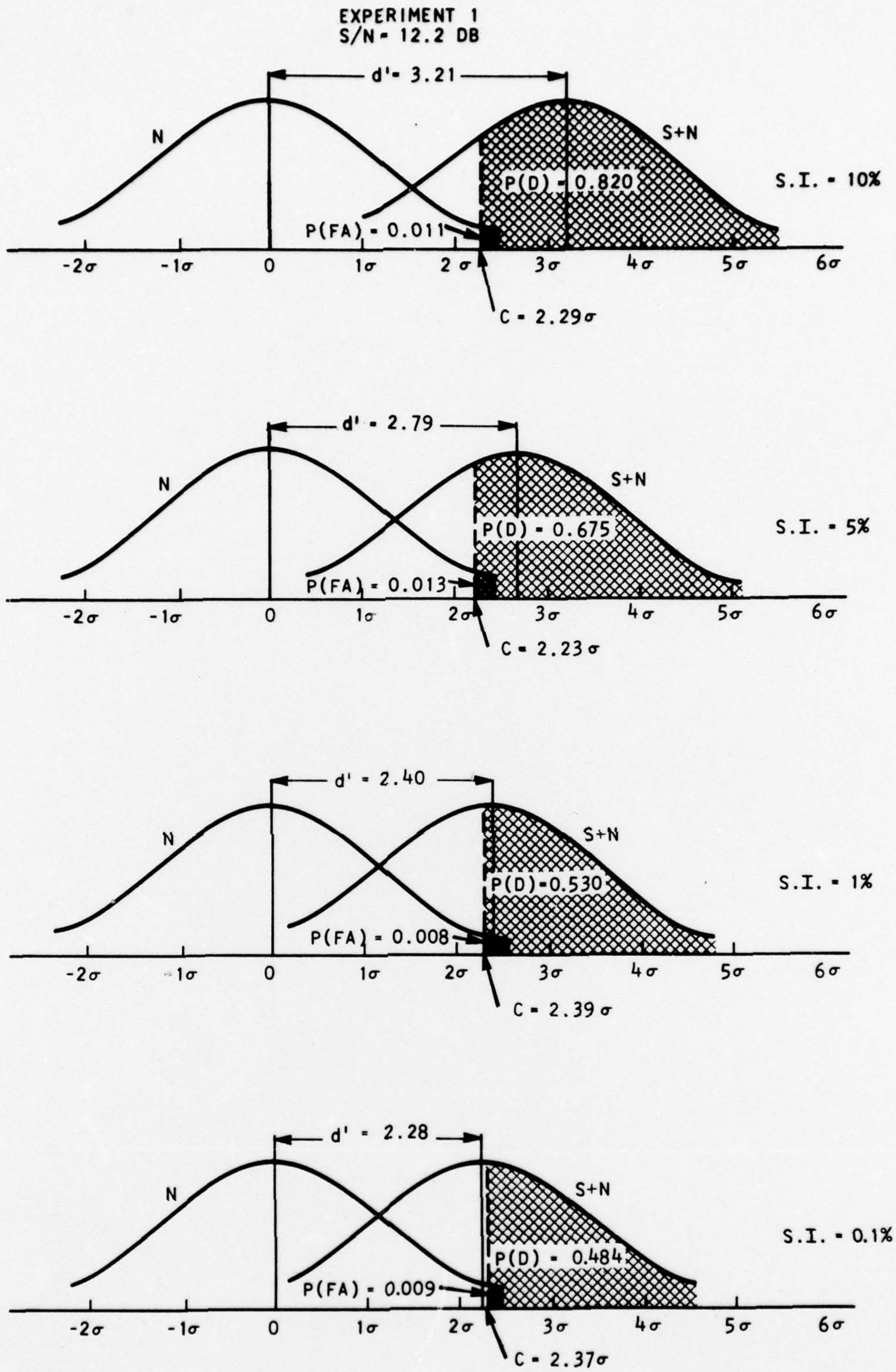

FIG. 9 - ASSUMED NORMAL NOISE (N) AND SIGNAL PLUS NOISE (S+N) DISTRIBUTIONS FOR VARIOUS SIGNAL INCIDENCES (S.I.). THE OBSERVER'S CRITERION (C) IS SHOWN AS A BROKEN LINE.

EXPERIMENT 2
S/N = 10.5 DB

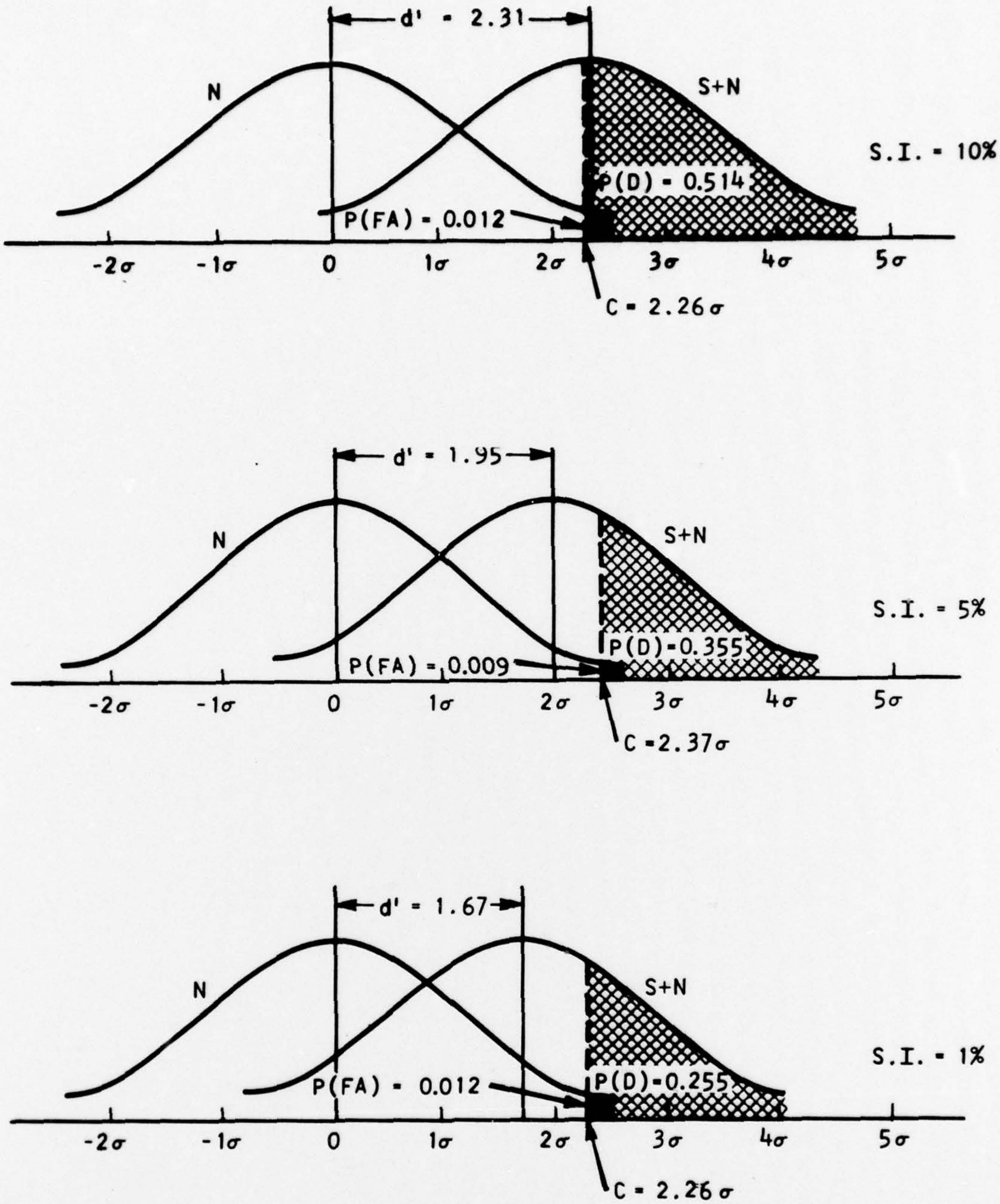

FIG. 10 - ASSUMED NORMAL NOISE (N) AND SIGNAL PLUS NOISE (S+N) DISTRIBUTIONS FOR VARIOUS SIGNAL INCIDENCES (S.I.). THE OBSERVER'S CRITERION (C) IS SHOWN AS A BROKEN LINE.

effective S/N is decreasing as SI decreases. This indicates that as the SI decreases a greater actual value of S/N is required for the observer to discriminate between signal-plus-noise and noise alone situations with the same likelihood of success. There is almost no change in the position of the observer's criterion C for the various SI.

Data for 50% SI at the same S/N are not included in this report since it was not felt to be compatible with the other data. The values obtained for d′ were but marginally greater than those for 10% SI; however in most cases either P(FA) was too large (greater than 1%) or P(D) was less than for 10% SI. The 50% SI situation does not seem to offer the same challenge to observers as a low SI condition. Consequently they do not operate at their peak capability.

4. CONCLUSIONS

On the basis of the experiments reported here it is concluded that:

1. The probability of detecting a signal at a constant value of S/N decreases as the signal incidence decreases.

2. The rate of decrease of probability of detection and detectability index as signal incidence decreases from 10% to 0.1% is constant.

3. The probability of detection does not approach zero for very small values of signal incidence.

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13. ABSTRACT

An experimental determination of probability of detection P(D) as a function of signal incidence, SI (how often a signal occurs) showed that:

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Probability of Detection						
Signal Incidence						
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